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ACOUSTIC PROPERTIES OF TURBOFAN INLETS

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INTRODUCTION

This report is a summary of the work completed under NASA Grant NSG 3036, entitled "Acoustic Properties of Turbofan Inlets" during the period September 1, 1980 to February 28, 1981. The work performed during this period is divided into the following four categories: 1) improvements to the new finite element codes including the use of Hermitian elements and numerical integration of element relations, 2) resolution of the question of efficiency of real variable vs. complex variable formulation, 3) implementation of GTICES, 4) preparation of an AIAA abstract.

FINITE ELEMENT CODES

Throughout the course of this investigation, the finite element method (FEM) has been used as a technique for solving the acoustic equations within the inlet duct. As described in previous reports the procedure for application of the finite element method consists of 6 steps: 1) subdivision of the domain into finite elements 2) selection of interpolation functions, 3) calculation of element equations, 4) assembly of element equation to form a global (matrix) equation, 5) solution of global matrix equation, and 6) calculation of additional variables. Items 1,2, and 3 are usually performed as separate operations. Items 5, and 6 are usually subroutines of the finite element computer codes and are improved regularly without disturbing the essential structure of the codes. Item number 4 is the backbone of any FEM, and any change in the approach to the assembly routine requires the development of a new set of computer codes.

During the course of this investigation, three separate approaches to the problem of assembling the individual elements into a global matrix have been developed. The original approach (FEM 1), developed in 1977, used only linear elements (item 2) and were very efficient. Unfortunately, these codes lacked versatility and could not assemble higher order elements without complete reprogramming. Thus, a more versatile set of codes (FEM 2) was prepared in 1978 which could assemble either linear or quadratic elements. These codes were not very efficient, however, resulting in longer run times and larger mass storage requirements. In an effort to combine the best qualities of FEM 1 and FEM 2, preparation of a new set of codes began in 1979. These new codes are now substantially complete. They are more versatile than FEM 1 in that they can assemble linear, quadratic, or Hermitian elements and can be easily modified to consider other higher order element relations. They are more efficient than FEM 2 in that the execution times for these more versatile codes are somewhat less than the execution lines for FEM 1. The new codes have combined the advantages of FEM 1 and FEM 2 without the disadvantages of either.

Some additional improvements are listed below.

Numerical Integration of Element Relations

When linear elements are employed, (Item 2) the integration of the weighted governing equations over a typical element (Item 3) are straightforward, resulting in simple algebraic expressions. For quadratic elements, the algebra is more tedious, but the resulting equations are still reasonable. These algebraic expressions are presented in Reference 1. For

higher order elements, the algebra becomes overpowering, the chance for error increases and the computation times increase enormously. For this reason, it is standard practice among structural finite element programmers to employ numerical quadrature techniques.

Since the approximating functions (linear, quadratic or Hermitian) are polynomials, the correct Gauss-Legendre numerical quadrature scheme will give the exact value for each element without resorting to tedious algebra and with a reduction in computation time. A computer subroutine using a 4th order Gauss-Legendre quadrature scheme is included in the FEM codes. This quadrature scheme will calculate exact element relations for linear, quadratic, and Hermitian elements. This subroutine has been debugged and extensively tested.

Lined Walls

The computer codes have provisions for acoustic liners on the boundaries using the principle of continuity of particle displacement. In the presence of a steady flow, either quadratic or Hermitian elements can be used. This subroutine has not been verified at this time.

REAL - VS - COMPLEX ARITHMETIC

It has been claimed by others[2] that real variable programming is inefficient, and substantial improvements with regard to mass storage and computation times can be achieved by using complex notation. It has been our opinion, based on the advice of our computer advisors, that on the CDC computers, real variable notation was more efficient. While some computers are "hard wired" for complex arithmetic, CDC (and certain other) computers perform complex arithmetic using external subroutines. Since the use of external subroutines is time consuming, it is preferable to use real variable arithmetic.

In our last report[3] we noted that the new finite element codes (FEM3) using complex variables were slightly (about 10%) faster than FEM 1 codes using real variable notation. Because the codes were different, no exact comparison could be made.

For reasons to be described in the next section, the new codes have been prepared in two forms: one uses complex notation and arithmetic, while the second form uses only real variable arithmetic. The computation times were found to be:

Complex arithmetic:	49 cpu secs
Real arithmetic:	27 cpu secs

Thus, <u>on a CDC computer</u> the use of complex arithmetic uses twice the time of the identical program using real arithmetic. Therefore, all calculations will be carried out using real variable arithmetic.

INTRODUCTION OF ICES

Both finite elements and finite differences have been used successfully to describe sound propagation in ducts. Both procedures approximate the exact potential (or pressure) by a large number of discrete values of the potential (or pressure) within the duct. Since it takes approximately 6 to 10 discrete values to describe one cycle of a sine wave, an equal number of points must be used for each wavelength of sound. Thus, as the frequency of the sound propagating in the duct increases, the number of discrete points or subdivisions must increase. This in turn increases the size of the matrix which must be inverted, the amount of data which must be stored in the computers memory, and the computation times. Limitations on the amount of mass storage available, limit computations to relatively low dimensionless frequencies ($W \sim 15$). It is this limitation on mass storage which has severely restricted the usefulness of the steady state finite element and finite difference formulations.

Since computers can store data on disks or magnetic tapes, the actual mass storage capability of a modern high speed computer is virtually unlimited. The limitation arises through the operating system which only permits access to data stored on the active disk at the time of execution. Thus if the operating system is modified to permit transfer of additional mass storage to and from magnetic tapes, the available mass storage will increase and calculations can be carried out at higher frequencies.

This problem of assembling and storing large finite element programs has been previously addressed by civil engineers. In fact, the majority of the development of the finite element method as an engineering tool has been carried out by structural engineers. The basic concept of a finite element

originated from a simple structural problem. This concept was developed into a general method for structural analysis and later into a universal technique applicable to fluid mechanics, acoustics, and other engineering disciplines.

The motivation for the development of the FEM was the need to analyze very large structures. Due to the size and complex geometrics of these structures, the stress matrices contained more nodal points than the computer could maintain in active memory. To overcome these difficulties, the Civil Engineering Department at MIT developed an operating system called ICES (Integrated Civil Engineering System) which can access memory stored on peripheral equipment such as magnetic tape or discs. An improved version of this system, known as GTICES, is available on the Georgia Tech Cyber 70/74. The Civil Engineering Department employs a fulltime research engineer, David Green, who is responsible for maintaining and updating this system. During the past three months, we have been working closely with Mr. Green in adapting the FEM acoustic codes to the GTICES system.

In order to modify the codes to make them compatible with the GTICES system several detail changes are being made. Since the GTICES system can only access real variables the codes which were written using complex variables have been rewritten using only real variables. As previously reported, this change brought about a 40% reduction in execution time. A necessary change from FORTRAN V to FORTRAN IV language should be fairly routine. With these changes the codes will execute under the GTICES system. However, the execution times for programs executed under GTICES are very dependent on the ordering and structure of the

program. Thus, considerable time must be spent in re-ordering the arrays and order of operations. As an example, under the normal operating system, the coordinates of node 100 are located in two arrays as follows:

X = XA(100)

R = RA(100)

Under the GTICES system it is considerably more efficient to store the location in a single two dimensional array as follows:

X = XR(100,1)

R = XR(100,2)

Efforts are now underway to re-structure the program to obtain the most efficient use of array storage.

AIAA ABSTRACT

In the previous progress report we described the results of a successful iterative scheme for combining the FEM with an integral technique. An abstract describing this procedure has been submitted for presentation at the AIAA Aeroacoustics Conference.

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